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REGIONAL DEER-VEHICLE ACCIDENT RESEARCH

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16. Abstract

The purpose of this study was to evaluate and test the effectiveness of methods, devices, or structures related to reducing the number of deer-vehicle accidents. Consistent with this purpose was the need to locate and examine potentially critical deer-vehicle accident areas and recommend methods or structures which could have reduced these accidents. In addition, the effects of the methods recommended and investigation of deer responses to various experimental structures was conducted.

This report summarizes the five areas of research performed under this study and will be published as Volume I of a 2 Volume Report. Volume II will consist of several parts - each a reprint of the technical articles published on the experimental features studied. Specifically, methods, devices, or structures outlined in the study proposal were as follows: A. Underpasses and Overpasses; B. Deer Guards; C. Deer Fence Length; D. Highway Lighting; E. Animated Deer Crossing Sign.

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REGIONAL DEER-VEHICLE ACCIDENT RESEARCH[a]

Dale F. Reed, Thomas N. Woodard, and Thomas D. I. Beck[b]

INTRODUCTION

The problem of deer (*Odocoileus* spp.)-vehicle accidents has been documented (Thompson 1967, Puglisi et al. 1974). Besides the loss of the biotic resource, considerable personal property damage is incurred (Woodard and Reed 1974). The problem arises when highways are constructed through habitats where deer are concentrated or when highways bisect deer migration routes.

Successful attempts to mitigate this problem were not initiated until the 1960's (Pojar et al. 1972, Reed et al. 1975). Some techniques such as reflectors have not been successful (Gordon 1969). Other techniques have produced contradictory results. Mansfield and Miller (1975) concluded that 76 x 76 cm symbol-type warning signs reduced deer-vehicle accidents in 11 of 19 study areas in California. Pojar et al. (1975) found that lighted, animated deer crossing signs did not significantly reduce deer-vehicle accidents in Colorado. This study utilized an evaluation technique which eliminated biases due to annual variations whereas the California study did not. This may explain some of the differences in results.

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[a]Covers a period from November 11, 1974 to November 11, 1979. The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration.

[b]All were wildlife researchers with the Colorado Division of Wildlife.

Müller (1967) found that 80 percent of vehicle accidents involving game in Switzerland occurred from sunset to sunrise. More than 92 percent of a sample of 1,441 deer killed on Colorado highways were killed from 1700 to 0900 MST (Myers 1970). It is plausible that such accidents could be reduced by use of highway lighting which would increase motorist response and decrease the number and severity of deer-vehicle accidents. Helms (1969) discussed factors which affect visual acuity. Brightness is equated with light reflecting from the object. Excessive brightness is detrimental to visual acuity. Contrasts in seeing surface detail and in outline delineation are important. Farber et al. (1971) further discussed the complexity of visibility on illuminated highways. Factors which interact to affect visibility, contrast of a target object with its surroundings, include amount and uniformity of fixed illumination, amount of vehicle lighting, target object's location in relation to fixed illumination sources and vehicle, pavement and object reflectance properties, and level of disability glare. Gallagher et al. (1972), after a review of pertinent literature, concluded that urban roadway lighting reduced occurrence of the more serious accidents, especially those involving pedestrians. Reductions from 30 to 80 percent were found. Rumar (1975) indicated many investigations demonstrated roughly 30 to 65 percent accident reduction under road lighting conditions. There has been no research to determine effect of highway illumination on occurrence of deer-vehicle accidents, but factors involved in pedestrian-vehicle accidents are similar. Installation of fixed illumination would enhance night visibility of the motorist and possibly reduce occurrence of deer-vehicle accidents.

Fences that restrict deer from getting onto highways may be used when other methods are not effective. Thompson (1967) reported that the use of fencing for critical deer-vehicle accident areas increased in 1967. Various types of fencing have been used. Puglisi et al. (1974) reported on the relationship of deer-vehicle accidents to four types of fencing installed adjacent to Interstate 80 (I-80) in Pennsylvania. The fences were 1.2, 1.5, 1.7, and 2.3 m high. The greatest number of deer-vehicle accidents occurred adjacent to the 2.3-m fence, apparently because this type of fence was installed in areas where the most critical deer-vehicle accident areas occurred. Falk (1975, unpublished data, Pennsylvania State University, University Park, Pennsylvania) observed deer jumping through this fence between wire strands near the top. In another study fences 2.13 m in height along the New York Thruway reduced collisions with white-tailed deer by 44.3 to 83.9 percent in the fenced areas and 12.9 to 24.7 percent beyond the ends of the fences (Free and Severinghaus, undated). More recently, Ward et al. (1979) reported on 12.6 km of 2.44 m fencing on both sides of I-80 in Wyoming.

While some fences prevent animals from going where not desired, a problem arises when it is necessary to permit vehicle access through the fences. When gates hinder vehicular traffic flow, structures such as modified cattle guards have been used and recommended. The physical requirements of guards to preclude deer crossings have not been established.

Used primarily in conjunction with sufficiently high and adequately maintained fences, underpasses and overpasses may provide alternatives to deer from getting onto highways and from having their movements and migration disrupted. Child (1974) reported on the reaction of caribou

(*Rangifer tarandus*) to simulated pipeline over-head structures. Mansfield and Miller (1975) reported light deer use through 18 highway metal pipe culverts and a 1.83 x 1.83 x 15.24 m (height x width x length) concrete box underpass. 2.44 m fencing was not used in conjunction with these structures. A study of a highway underpass (Reed et al. 1975) indicated a reluctance of deer during use. It has been surmised that overpasses (no substantial overhead structures) would be used more readily by deer. Klein (1971) reported on bridges used by reindeer (*Rangifer tarandus*) in Norway. The width of the bridge was reported to be dependent upon the size of the herd to be moved (i.e. 10–15 m wide for herds numbering up to 2000), since reindeer tend to bunch up when crossing and may force each other over the edges if the bridges are too narrow. Bridge surfaces were covered with soil. Location was critical to the success of the bridges. Child (1974) reported on caribou response to two gravel ramps of 30.5 m and 22.9 m lengths and 2.4 m heights over a simulated pipeline. The dimensions and design of underpasses and overpasses that are most effective for wild ungulate use are largely unknown.

The purpose of this study was to evaluate and test the effectiveness of methods, devices, or structures related to reducing the number of deer-vehicle accidents. Consistent with this purpose was the need to locate and examine potentially critical deer-vehicle accident areas and recommend methods or structures which could have reduced deer-vehicle accidents in these areas. Subsequently, measurement of the effects of methods recommended and investigation of deer responses to various experimental structures was to be conducted. Specifically, methods, devices, or structures outlined in the study proposal[c] were as follows:

A. Underpasses and Overpasses

B. Deer Guards

C. Deer Fence Length

D. Highway Lighting

E. Animated Deer Crossing Sign

STUDY AREAS

Underpasses and Overpass

The underpass and overpass studies were located in several areas in western Colorado. Reed et al. (1975) described the study area of the Vail deer underpass. Eleven other underpass structures were monitored for deer use during various periods of time. Their approximate locations are as follows:

Avon	0.5 km east of Avon Interchange, I-70
Eagle East 1	5.2 km east of Eagle Interchange, I-70
Eagle East 2	3.7 km east of Eagle Interchange, I-70
Eagle West 1[d]	3.2 km west of Eagle Interchange, I-70
Eagle West 2[d]	5.5 km west of Eagle Interchange, I-70
Mamm Creek	6.4 km east of Rifle Interchange, I-70
Dry Creek	3.2 km east of Rifle Interchange, I-70
Arch Deer[d]	10.6 km west of Hesperus, U.S. 160
Salida 1	6.0 km southeast of Howard, Colorado 291
Salida 2	6.6 km southeast of Howard, Colorado 291
Chaffee Gulch	13.7 km north of Ridgway, U.S. 550

[c]Attachment to the Contract Agreement for a Cooperative study of Deer-vehicle Addicents Project HPR-3(3).

[d]Constructed specifically for deer use.

The overpass study was conducted 7.5 km west of Vail adjacent to I—70. The structure spans Gore Creek and was used by vehicles before the completion of I—70. Approximately 4.8 km of associated 2.44—m fencing generally parallels the highway in both directions east of the overpass. Deer apparently move around the west ends of this fencing and cross the bridge overpass rather than Gore Creek.

Deer Guards

Two deer guards were installed in 2.44 m fences, one in the fence adjacent to I70 near Avon, Colorado and the other in a Bureau of Land Management wildlife exclosure fence at Trail Gulch between Dotsero and Burns, Colorado. Both were monitored for deer use under field conditions (Reed et al. 1974G). The guard at Trail Gulch was used for controlled tests (prototypes I—V).

Deer Fence Length

The 2.44 m fencing study areas were located in six areas between Vail and Aspen. They were the Vail, Avon, Edwards, Eagle, Diamond S, and Carbondale 2.44 m fences.

The Vail 2.44 m fence was located between the west Vail Interchange and somewhat east of the Dowd Junction bridge. The 5.6 km section of interstate that includes the fences and associated deer underpass was accepted for completion by the Federal Highway Administration on August 26, 1970. The location utilizes well-established deer migration trails and a natural drainage referred to as Mud Springs Gulch. Approximately 4.8 km of fencing generally parallels the highway in both directions from the underpass. The fencing on both sides of the highway joins chain-link fences near the West Vail Interchange. One-way deer gates were strategically located in the fences (Reed et al. 1974a).

The Avon study area consisted of a segment of the interstate from the Avon Interchange east 3.6 km to the Eagle River Bridge and was opened to traffic October 1, 1971. The 2.44 m fence was completed along the north highway right-of-way on October 5, 1972. Open sagebrush areas and various browse species are common on the north side of the highway. Alfalfa fields are prevalent south of the highway. Deer inhabit this area from August until snow depth precludes use, usually by late December.

The Edwards study area consisted of a segment of the interstate from the Edwards Interchange west 3.6 km and was opened to traffic October 1, 1971. The 2.44 m fence was completed along the north highway right-of-way in July, 1972. Deer utilize the area adjacent the highway to the north during the winter. Sagebrush flats and pinyon-juniper communities are common.

The Eagle study area consisted of a segment of the interstate from near the Eagle Interchange east 7.7 km. The interstate highway was opened to traffic October 5, 1972. The 2.44 m fence was completed along the north side of the highway right-of-way October 5, 1973. Alfalfa fields are prevalent south of the highway. Pinyon-juniper and some big sagebrush occur on the north.

The Diamond S study area consisted of a 4-lane 1.8 km long segment of Highway 82 adjacent to the Diamond S Ranch, approximately 1.6 km northwest of the junction with Highway 133. A field of crested wheatgrass (<u>Agropyron desertorum</u>) is located on the east side of the highway and is one of the earliest grasses to green up in the spring (Reynolds and Springfield 1953). Sagebrush is abundant around the perimeter of the crested wheatgrass field and is replaced by pinyon-juniper type as elevation increases to the east. Alfalfa fields line the west side of the highway. Deer concentrate in the crested wheatgrass field and sagebrush east of the highway in late winter and early spring.

The Carbondale study area consisted of a segment of Highway 82 from about 1.3 km southeast of the junction with Highway 133 to about 0.2 km up Crystal Springs Road. The 2.44 m fence was completed along the north side of the highway right-of-way October 17, 1974. Alfalfa fields are prevalent north of the highway with big sagebrush occurring on an abbreviated south facing slope behind the fence.

Highway Lighting

The highway lighting study area was located 4.8 km south of Glenwood Springs, Colorado on State Highway 82. The 1.2 km segment of highway had 4 lanes and a posted speed limit of 88.5 km per hour. The average daily traffic volume within 4.0 km of the study area was 5,706, 5,111, 6,221, and 6,483 during the 1974, 1975, 1978, and 1979 January-March periods, respectively. Deer generally winter in the vicinity of the study area from mid-January to late March. A more extensive description of the study area was provided by Reed et al. (1977) and Reed and Woodard (1981).

Animated Deer Crossing Sign

The animated deer crossing sign study area encompassed the same area described above for the highway lighting study. The 2.4 km segment of highway had a posted speed limit of 96.5 km per hour. The average daily traffic volume within 4.0 km of the area was 4,283 and 4,836 during 1972 and 1973 January-March periods, respectively. A more extensive description of the study area was provided by Pojar et al. (1975).

METHODS

Underpasses and Overpass

The methods used in studying the Vail deer underpass were described by Reed et al. (1975) and Reed (1981a). The eleven other underpasses were checked for deer tracks periodically throughout the year and weekly or more often during deer concentration periods. Trackbeds were maintained when possible by raking the soil at the entrances of the structures. Only one overpass became available for study. On June 7, 1974 it was discovered that deer were using a sub-standard bridge, 3.2 x 4.9 x 13.4 m, height (underbridge clearance) x width x length (direction of traffic), over Gore Creek. Approaches to the overpass were checked for deer tracks and a video time-lapse surveillance system (Reed et al. 1973) was used to record imagery of crossings and overt behavioral responses during spring-summer (June-July) and fall (October-November) migration periods. During 1976 the bridge was modified (deck removed and re-built) so the width of the structure could be varied. It was designed to have the width (control = 4.93 m, variable = 2.48 m) (Fig. 1) changed for alternate three day periods. During 1978 an overhead netting, supported by arched plastic tubing (Fig. 2), was designed to be assembled (variable) or disassembled (control) for alternate three day periods. The number of video-recorded deer approaches, entrances, exits, and behavioral responses including muzzle-to-ground (Reed et al. 1975:366), hesitation (cessation of forward movement for 1.0 second or more), and crossing mode (walk, trot, or bound) were tallied during video tape replay.

Deer Guards

The first guard design (prototype I) utilized 3.05 x 3.66 m guard sections constructed with flat mill steel 1.3 x 10.2 x 304.8 cm (width x height x length) rails. A 3.05 x 17.98 m (width x length) runway was constructed with 2.44 m fencing attached to one end of the guard at Trail Gulch. The test involved releasing deer in the runway and observing their response as they attempted to escape via their only exit across the guard (Reed et al. 1974G). Other guard design prototypes (II, III, IV, and V) were tested using the same location and methodology.

Prototype II was an alternate black and white pattern with 30 cm long alternating black and white sections painted on each rail of the first 3.05 x 3.66 m section of the prototype I guard. Prototype III was rubber tubing (five large tire innertubes cut and sectioned longitudinally to form elongated rectangles when stretched) stretched across and 15 cm above the prototype II guard. Prototype IV was rubber straps (93 ten-speed bicycle tire tubes) stretched parallel and next to each other across and 15 cm above the prototype II guard. Prototype V was a black and white scintillation or "ray pattern" (Teuber 1974:104) originally developed by Mackay (1957) painted on a 3.05 x 3.66 m tarp and placed over the prototype I guard at the end of the runway. The principle behind the use of this design was the stimulation of the line-detecting mechanism of form perception which causes a scintillation effect in human vision (Teuber 1974:104). It was hypothesized this effect would be similarily detected by deer and adverse reactions potentially elicited.

Deer Fence Length

Deer density adjacent to the 2.44 m fences except for the Vail fence was estimated using the method described by Reed (1969). Locations of vehicle-killed deer were documented in relation to quarter-mile markers or known structures for all the fences. Track counts were made in the median of Highway 82 adjacent to the Diamond S fence. Conditions were normally favorable for maintenance of soil in the median during March, April, and May when most of the deer activity occurred.

Deer were marked with numbered neck bands or automatic tagging devices (Siglin 1966) at the Vail and Avon fences. The automatic tagging devices were often placed on one-way deer gates (Reed et al. 1974a) located in the 2.44 m fences. A drop-net was used in 1971 to capture deer when they frequented areas behind the 2.44 m fence that lead to the Vail deer underpass. Clover traps (Clover 1956) were used to trap deer on the winter range adjacent to the Edwards and Eagle fences. A CAP-Chur gun using succinylcholine chloride in Pneu-Darts was used to capture selected animals. Radio-tracking transmitter collars (Model MK 3, Telonics, 1300 W. University, Mesa, AZ 85201) were placed on does trapped or captured behind the I-70 Eagle fence. Attempts were made to locate these animals by establishing bearings from several prominent observation points. These bearings were plotted on copies of a U.S. Geological Survey quadrangle map (scale 1:24,000). Telemetered animal locations were estimated by determining the area where two or more bearings converged. Locations or sightings of marked deer in the vicinity of the 2.44 m fence were used to estimate their movements in relation to the fence.

One-way deer gates (Fig. 3) were located in the Vail, Avon, Edwards, and Eagle 2.44 m fences. These gates were checked periodically for passages and activity by checking tracks in the raked soil at the gate entrance and exit.

The methods used in calculating benefit-costs of fencing and other methods was described by Reed et al. 1981.

Highway Lighting

Thirteen, 37,000-lumen, 700-watt, clear, mercury vapor luminaires (lamps) mounted on 3.05 m arms at the top of 12.2 m metal poles were used to light the highway. Nine lamps were spaced at approximately equal intervals (59.2 to 68.9 m) to illuminate about 0.50 km of highway (full lighting). At the ends of the full lighting were areas of transition lighting, created by additional lamps spaced approximately 119 m and 302 m out from the last full lighting lamp (Fig. 4).

The lights were alternately turned on and off for one week periods during January through March or into April of 1974 through 1979. Horizontal illumination levels were measured with a General Electric SL480A light meter. Luminance measurements were taken at sites where the accidents occurred. Luminance values (foot-lamberts (fL)) were recorded with a spotmeter (Spectra Model UBA) (Fig. 5), and were taken on a target at the kill site and on the background to approximate the view of an approaching motorist when the lights were on. The target was a simulation of a female mule deer (transverse section of full taxidermy mount). Target readings were taken from a height of 1.3 m and a distance of 15.0 m, resulting in a measurement area diameter of 26.0 cm midway between the shoulder and hip. Background readings were taken at the same height and a distance of 60.0 m, resulting in a measurement area diameter of 102.0 cm. The taxidermy mount was removed during this background measurement. Measurements were taken between 0300 and 0600 MST to minimize traffic interference. No measurements were taken when vehicle headlights or other spurious light sources were present. Background luminance (Lb) and target luminance (Lt) measurements were transformed into visibility indices (VI) by the following equation (Gallagher and Meguire 1974):

$$VI = \frac{C(RCS_{Lb})}{5.74} (DGF)$$

$$\text{where } C = \frac{Lt-Lb}{Lb} ,$$

RCS_{Lb} = Relative contrast sensitivity for the recorded background luminance,

and DGF = Disability glare factor = 1.0

RCS values were obtained or extrapolated from published tables (Gallagher and Meguire 1974, Technical Committee of the CIE 1972).

Additional methods used were described by Reed et al. (1977) and Reed and Woodard (1981).

Animated Deer Crossing Sign

The lighted, animated deer crossing sign (Fig. 6) had a reflectorized yellow, diamond-shaped background (1.83 x 1.83 m) with four silhouettes of deer made of neon tubing lighted in sequence from right to left across the sign. Two signs were constructed so they could be easily swung away from approaching traffic. In the on position, the signs were locked into place facing traffic and the neon lights were activated. The signs were turned on and off for alternate weekly periods during January - March periods. Other methods were similar to those used during the highway lighting tests and are described further by Pojar et al. (1975).

DATA ANALYSIS

Underpasses

Data analysis covering the Vail deer underpass was reported by Reed et al. (1975) and Reed (1981a). Eleven other underpasses were checked for deer use during the period covered by this report. Numbers of deer passages recorded varied considerably (Table 1). Moderate numbers (30—90) of passages occurred per annum through the Avon underpass since deer use of the structure was discovered on October 25, 1975, except for 1979. During 1979 the construction of the Avon airport and related buildings may have precluded regular use of the structure. Observations of a neckbanded doe (No. 27) indicated that most passages occurred as a result of nightly use of the structure by a small sub-group of deer. Deer passages through a small structure such as this are probably limited to few deer and a low percent of the nearby population. Of those structures under I—70, only three (Vail, Eagle West 1, and Eagle West 2) were constructed specifically for deer use (Table 1). The reluctance of deer at the Vail structure has been discussed (Reed et al. 1975 and Reed 1981a). Such reluctance did not appear to be present at the Eagle West structures. Trails established by deer passage through the underpasses were distinct and there was no "milling about" detected at the entrances.

The primary stimulus of a given underpass structure to approaching deer may be termed the "openness effect." Calculated as follows:

$$\frac{\text{height x width (or open-end surface area)}}{\text{length}}$$

the openness effects of the Vail and Eagle West underpasses were 0.31, 4.57, and 5.57 (metric measurements), respectively (Table 1). There are several factors to consider before relating openness effect to deer behavioral response. Additionally, any reasonable attempt to relate openness effect to deer use must consider deer density and motivation at the structure. Statistical analysis of openness effect as related to deer passage success (i.e. regression analysis, etc.) would require more data points than obtained in this study.

Overpass

The video time-lapse surveillance system was operated at the overpass 1.) during four seasons, fall 1974, spring-summer and fall 1975, and spring-summer 1976, to collect pre-experimental crossings and behavioral data, 2.) during four seasons, fall 1976, spring-summer and fall 1977, and spring-summer 1978, to collect experimental width crossings and behavioral data, and 3.) during two seasons, fall 1978 and spring-summer 1979, to collect experimental overhead netting crossings and behavioral data. A total of 570 crossings were examined during video replay (Tables 2–4).

Number of Crossings

There were 329 deer crossings over the bridge during the pre-experimental period (Table 2). For purposes of examining variability in the number of crossings during alternate three-day periods (control-variable scheme to be used in experimental tests), these data were categorized into alternate three-day periods and tested for independence. They were significantly different ($X^2 = 19.6$, df = 4, $P < 0.005$).

During the experimental width tests (control width = 4.93 m, variable width = 2.48 m), more crossings occurred under control than under variable width during each of the four seasons (Table 3). A test for independence shows that the difference between the number of control and variable crossings during the alternate three-day periods was not significant ($\chi^2 = 8.0$, df = 4, $P > 0.05$).

During the experimental overhead netting tests (control = netting disassembled, variable = netting assembled), more crossings occured under control than under variable during each of the two seasons (Table 4). A test for independence shows that the difference between the number of control and variable crossings during the alternate three-day periods was not significant ($X^2 = 1.4$, df = 3, $P > 0.50$).

The difference between the number of control and variable crossings in the pre-experimental seasons was sufficient to indicate that the variability was due to the number of animals within periods rather than the structure. Basically, the number of animals within periods was independent (significantly different) before the experimental tests and dependent (not significantly different) during the experimental tests. It is uncertain whether this dependence can be related to reluctance of deer to use the narrower bridge or the bridge with overhead netting.

Crossings:Approach Ratios

During the experimental width tests, fewer approaches of both types (Table 3) occurred during control (15) than during variable (35). The control crossings per approach ratios were significantly ($P < 0.025$) greater than that for variable. Generally, this would be expected if there were a greater reluctance of deer to cross a narrower structure (i.e. more reluctant animals either approached and failed to cross, or made more than one approach before crossing).

During the experimental overhead netting tests, more crossings and approaches (Table 4) occurred during control (43 and 24 respectively) than during variable (18 and 17 respectively). However, variable crossings per approach ratios were not significantly ($P > 0.050$) smaller than that for control. Generally, it would be expected that the variable ratio would be smaller if there were a greater reluctance of deer to cross under a net arch (i.e. more reluctant animals either approached and failed to cross, or made more than one approach before crossing).

The importance of ratio differences, however, is diminished if the differences in the number of crossings were due to unexplained variability.

Duration of Hesitations and Crossings

During the experimental width tests, the control and the variable means of the combined seasons (Table 5) of both the duration of hesitations and the duration of crossings are not significantly different ($P > 0.20$ and $P > 0.10$, respectively). Generally, if the narrower width was expected to result in more reluctance to cross, then longer hesitations would be expected. The means, except for the spring of 1977, support this trend. Reasons for the exception in the spring of 1977 are unknown. In all of the seasons except one (fall of 1976) the variable had shorter mean crossing times. Animals being more reluctant in crossing the variable (narrower width) would be expected to do so more hurriedly (more and/or faster trotting and bounding).

During the experimental overhead netting tests, the control and the variable means of the combined seasons (Table 6) of both the duration of hesitations and the duration of crossings were not significantly different ($P > 0.20$ and $P > 0.40$, respectively). Generally, if the net arch was expected to result in more reluctance to cross, then longer hesitations would be expected. The means for the duration of hesitations for the fall of 1978 were not significantly different ($P > 0.20$). However, the variable mean was significantly ($P < 0.05$) less in the spring of 1979. Also animals being more reluctant in crossing under the netting (variable) would be expected to do so more hurriedly (more and/or faster trotting and bounding). The duration of crossings under the netting (variable) for the fall of 1978 were significantly ($P < 0.05$) greater than the control, whereas the duration of crossings for the spring of 1979 were not significantly ($P > 0.50$) different.

Differences between the spring and fall migrations are perplexing. The variable mean of duration of hesitations and the variable mean of duration of crossings were both significantly ($P < 0.05$) greater in the fall of 1978 than in the spring of 1979, whereas the control mean of duration of hesitations and control mean of duration of crossings were not significantly ($P > 0.05$ and $P > 0.50$, respectively) different. Possibly the data of the two seasons should not be combined. The differences may be related to the observed and postulated dissimilarities between the seasons, some of which are as follows:

Fall	Spring
First overhead net experience	Potentially second overhead net experience
Good physical condition	Poor physical condition
High wariness (hunting related)	Moderate wariness
Most mature females with fawns at side	Most mature females parturient
Maternal-fawn bond strong	Maternal-yearling bond weak
No dawn activity	Dawn activity
Very high motivation to migrate (more direct movements and less time consumption likely, casually related to increasingly inclement weather)	High motivation to migrate (more indirect movements and more time consumption likely, casually related to weather)
Low stream flow in Gore Creek	High-turbulent stream flow in Gore Creek

Behavioral Responses:Crossing Ratios

During the experimental width tests, there were more animals exhibiting behavioral responses (BR) and more instances of behavioral responses per crossings (C) during variable than control for each of the responses studied (Table 7). Although the ratios for instances of behavioral response per crossing are larger for variable width in each case, they were not significantly larger ($P > 0.20$). Therefore, differences in these behavioral responses may be due to chance and not to the reluctance of animals in crossing a narrow bridge width.

During the experimental overhead netting tests, there were more animals exhibiting behavioral responses (BR) and more instances of behavioral responses per crossing (C) during variable than control for most of the responses studied (Table 8). Although the ratios for instances of behavioral response per crossing were larger for the variable except for muzzle-to-ground, they were not significant ($P > 0.50$). Therefore, differences in these behavioral responses may be due to chance and not to the reluctance of animals in crossing under a net arch.

Deer Guards

The first deer guard (prototype I) was tested during 1972-1973. Sixteen of eighteen deer released in the runway attached to the guard crossed voluntarily (Reed et al. 1974G). Four other prototypes were tested, prototype II and III in 1975, prototype IV in 1976, and prototype V in 1978.

Five of seven deer released in the runway attached to prototype II guard crossed voluntarily. They elicited only four instances of investigative behavior in apparent response to the structure. Two walked, two trotted, and one bounded across the guard (Table 9). Nine of 14 deer tested with prototype III crossed voluntarily, exhibiting 29 "bend-neck-look" instances of investigative behavior and 17 "walk-on" responses. Six of the animals walked, one trotted, and two bounded across the guard (Table 10). Five of eight deer tested with prototype IV guard crossed voluntarily, exhibiting eight "bend-neck-look" instances of investigative behavior and three "walk-on" responses. One of the animals walked, two trotted, and two bounded across the guard (Table 11). All four deer tested with prototype V guard crossed voluntarily, exhibiting 27 "bend-neck-look" instances of investigative behavior and six "walk-on" responses. Three of the animals walked and one bounded across the guard (Table 12).

Ratios, including "bend-neck-looks" per crossing, "walk-ons" per crossing, and crossings per involuntary or no crossing, for the deer guard prototypes are presented in Table 13.

Deer Fence Length

Six 2.44 m fences were evaluated as to the reduction of deer-vehicle accidents after installation of the fences. The range of reduction was 67.8 to 86.5 percent with a cumulate average of 78.5 percent (Table 14). Since this evaluation is based upon year-to-year comparisons[e] the cumulative average has fluctuated annually throughout the evaluation. The winter of 1977 was exceptionally mild and probably resulted in fewer kills at some of the fences. Conversely, the winter of 1979 was

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[e]An acknowledged common fallacy in biological investigations is to compare groups separated by time. For evidence so obtained, cause-and-effect should be attributed cautiously.

exceptionally severe and probably resulted in more kills, especially at the Eagle 2.44 m fence. Data from severe winters were not discarded from the sample, similarly, data from mild winters should not be discarded either. Weather conditions, fence length (Table 14) and number and behavior of deer associated with the fenced areas were probably the major factors resulting in the varying degrees of accident reduction.

Adjacent to the Diamond S 2.44 m fence, deer normally concentrated in crested wheatgrass fields northeast of the highway in late winter and early spring. Mean number of deer crossings during March-May periods continued to increase (Table 15) in spite of the decrease in numbers of deer seen during spotlight counts.

Deer were neck banded with numbered collars (Fig. 7), automatic tagging devices and telemetry collars in the Vail, Avon, Edwards and Eagle 2.44 m fence areas. Numerous sightings and locations of these banded animals and direct observations of unbanded animals resulted in data on the movement of deer lateral or parallel to the Vail, Avon, and Eagle fences (Table 16). Females and males moved lateral to the fences for mean distances of 0.578 and 0.709 km, respectively.

Twenty-eight one-way deer gates were located in the Vail, Avon, Edwards and Eagle fences (Table 17). Reed et al. (1974a) reported on deer use of one-way gates in the Vail 2.44 m fence during 1970-1972. Since then the use of these gates has diminished substantially as deer apparently have adapted to the fencing-underpass complex and the increasing recreational-residential development. Deer use of the one-way gates in the Avon 2.44 m fence diminished in 1979 possibly because of the development of the Avon airport and associated buildings and chain-link fence.

Benefit-cost analysis of 2.44 m fencing and other methods was reported by Reed et al. (1981). Additionally, specifications and maintenance of deer (2.44 m) fences and associated structures were reported by Reed (1981G).

Highway Lighting

Deer crossings and accidents occurred in the study area in 1974, 1975, 1978, and 1979. The lights were evaluated for 56 weeks during these four years, 28 weeks with the lights off and 28 weeks with the lights on. The estimated deer crossings per accident with lights off was less than the ratio with the lights on, 55.1 and 66.9, respectively. However, the difference was not significant for any one of the years ($\chi^2 = 0.252 - 1.133$, $P > 0.25$), or for the composite of the four years ($\chi^2 = 0.781$, $P > 0.25$).

Lb and Lt measurements were made at each of the 39 accident sites, 26 in transition lighting and 13 in full lighting (Tables 18 and 19, respectively). It was hypothesized that these measurements would result in visibility indices that were lower in transition lighting than in full lighting, and that the former might have had to be discarded from the sample (i.e. transition lighting would not provide sufficient illumination for an adequate test). However, the means of the visibility indices (using absolute values) were 1.845 ($\pm$ SD 1.538) and 1.754 ($\pm$ SD 0.849) for transition and full lighting, respectively. The difference was not significant ($P > 0.50$). Hence, the transition lighting data were retained in the evaluation. Additional description of data analysis was provided by Reed et al. (1977) and Reed and Woodard (1981).

Animated Deer Crossing Sign

Signs were evaluated for 15 weeks during 1972 and 1973; eight weeks with the signs off and seven weeks with the signs on. The deer crossings per accident (deer kill) ratio with signs off was nearly identical to the ratio with the signs on, 56.5:1 and 56.9:1, respectively. By chi-square analysis, there was no significant difference ($P > 0.50$) between the crossings per kill ratios during 1972, 1973, or for the composite of the two years. A more detailed description of data analysis was provided by Pojar et al. (1975).

DISCUSSION AND RECOMMENDATIONS

Underpasses

Generally, it was found that mule deer continued to be reluctant in using relatively small underpasses. This reluctance ultimately worked against highway safety and the deer resource. Consequently, it is recommended that larger (openness effect > 0.6, metric measurements) underpasses be constructed where deer passage under the highway is needed. This recommendation is made for deer having high motivation to cross the highway alignment. It follows that deer having light to moderate motivation will require larger structures such as open-bridge underpasses (Fig. 8) where our data suggest little reluctance occurs. Additional discussions and recommendations regarding underpasses were reported by Reed et al. (1975), Reed et al. (1981), and Reed (1981a, 1981G).

Overpass

Based upon the overpass data analyses, it does not appear that an important level of reluctance of deer to bridge width was reached.

Further experimentation on the parameter of width was not considered practical since physical constraints did not allow a narrower (< 2.48m) width to be readily constructed and subsequently changed to a "control." Theoretically, there would be a point at which an overpass would be so long and narrow as to preclude deer crossings. Similar to the openness effect of underpasses, the primary stimulus of a given overpass structure to approaching deer may be termed the "bridge effect." Calculated as follows:

$$\frac{\text{width} \sqrt{\text{height}}}{\text{length}}$$

the bridge effects of the control and variable were 0.65 and 0.34 (metric measurements), respectively. In addition, it appears that deer were not reluctant to pass under an overhead netting designed to simulate a pedestrian-type overpass structure and wire mesh to prevent deer from jumping off and falling onto the roadway.

Generally, deer crossed the overpass with somewhat less reluctance than that exhibited during passages at the Vail underpass (i.e. the look-up behavior was essentially absent at the overpass, but common at the underpass (Reed et al. 1975)). Caution should be used when comparing these two structures since different dimensional parameters are involved.

Deer Guards

The first deer guard (prototype I) had limited effectiveness in preventing deer movements through openings in 2.44 m fences (Reed et al. 1974G). The other four prototypes were equally limited in preventing or discouraging deer movements through an opening in a 2.44 m fence under the conditions of these tests. Several other concepts for deer guard prototypes (e.g. Fig. 9) were not tested. However, based upon the responses of deer to various aspects of the five prototypes, it is estimated that they would not be effective. Where 2.44 m vehicle gates (manual, "push-type," or automatic) are not feasible, no effective guard can be recommended as a result of this study.

Deer Fence Length

Six 2.44 m fences having an average length of 3.5 km were effective in that fewer accidents occurred after installation of the fences. Although cause-and-effect should be attributed cautiously because of separation of groups by time, number of years (5—10) and different areas (6) studied tend to represent some of the variability that exist for application of this methodology. In order to maintain approximately 75 percent fewer accidents after installation, 2.44 m fences must be adequately resistant to deer passage. This can be accomplished by construction and maintenance (Reed 1981G) where adequate basal closure and permanency are provided.

Based upon the mean lateral movements of deer to 2.44 m fences, such fences should extend approximately 0.8 km beyond deer concentration areas, and pass structures (underpasses and overpasses) should be located at least every 1.6 km along the fence where deer passage or crossings are needed.

One-way gates were effective in allowing deer to escape the highway rights-of-way when they were strategically located. When one-way gates are recommended for installation in 2.44—m fences, they should be located near drainages or vegetative cover. Recommendations for spacing of the gates and other details were covered by Reed et al. (1974a) and Reed (1981G).

Highway Lighting

Visibility index means calculated in the lighting study are near the level where 70 percent of the motorists can see a target at satisfactory separation distance (Gallagher and Meguire 1974). To attain a level where 85—95 percent of the motorists can see a target at satisfactory separation distance, a visibility index value of 2.6 — 3.6 is required. Only 6 of the 39 indices were within or above this range (Table 18 and 19). Probably inherent in this problem was the drab pelage of deer which readily blended with the lighted highway surface when in certain locations. For example, accident 24 (Table 19) involved a target and background with very low contrast despite its occurrence under full lighting. At these locations, just beyond the lamps and when the background was relatively well lighted ($\sim$ 1.0 fc), it is estimated that an increase in horizontal illumination would not substantially increase the contrast or likelihood of motorist visual discrimination.

Since highway lighting was not effective as tested under the conditions of this study, it is not recommended as a method to reduce deer-vehicle accidents. Additional discussion is provided by Reed and Woodard (1981).

Animated Deer Crossing Sign

The lighted, animated deer crossing sign was not effective in reducing deer-vehicle accidents as tested under conditions of the study. Additional research should be conducted before signs are recommended as methods to reduce deer-vehicle accidents. Although additional sign research was provided for in the study proposal (i.e. test sign with advisory speed reduction on "educational" sign below animation), no additional research was conducted because the study area was occupied with the highway lighting portion of this study during each available season (1974-1979). Additional discussions and recommendations regarding the lighted, animated deer crossing sign were reported by Pojar et al. (1975).

CONCLUSIONS

Studies of the first three methods, devices, or structures (underpasses and overpasses, deer guards, and deer fence length) were undertaken to determine the efficacy of modifying deer behavior, or more specifically, of keeping deer off highways. Both qualitative and quantitative observations indicated that strategically located underpasses and overpasses with acceptable dimensions and characteristics were effective in providing deer with relatively safe passage to needed resources. Of the deer guard prototypes tested in this study none were effective in precluding deer movements. If simple and economically feasible guards are important to highway safety programs, additional research along new conceptual lines may be necessary. Segments of highway having deer fences were shown to have fewer accidents after fence installation. Generally, these fences have been effective in modifying deer movements, especially when used in conjunction with underpasses. It is imperative that such fencing be adequately constructed and regularly maintained.

Studies of the last two methods, devices, or structures (highway lighting and animated deer crossing sign) were undertaken to determine the efficacy of modifying motorist behavior. In the highway lighting study, it was hypothesized that, by lighting a deer crossing area, motorist's visibility would be sufficiently enhanced to allow timely target (deer) discrimination and consequent accident avoidance. Similarly, in the animated deer crossing sign study, it was hypothesized that animated warning signs would increase motorist awareness sufficiently to allow for accident avoidance. Neither study provided evidence to support these hypotheses. Apparently, any increased motorist awareness did not result in sufficient behavioral change to reduce accidents.

Of the five methods, devices, or structures tested, deer fencing (2.44 m in height), used in conjunction with strategically located underpasses and one-way deer gates, was the most effective.

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T A B L E S

and

F I G U R E S

Table 1. Highway underpasses, height and width dimensions, number of deer passages, openness of tunnel effect, and deer activity adjacent to the underpasses. Only the first two structures were intended for regular deer use.

Underpass	Height X Width [1] / length (m)	Number deer passages per year	Openness of tunnel effect (m)	Adjacent deer activity/2.44-m fencing adjacent structure
Vail deer [2]	$\frac{3.05 \times 3.05}{30.48}$	345.1 [3]	0.31	Concentrated, highly motivated migration/ both sides
Avon	$\frac{\pi(1.06)^2}{108.7}$	59.8	0.03	Moderate/one side
Eagle East 1	$\frac{4.27 \times 4.27}{45.58}$	3.0	0.42	Moderate/one side
Eagle East 2	$\frac{2.44 \times 2.44}{59.54}$	1.5	0.10	Moderate/one side
Eagle West 1 [4]	$\frac{(3.75 \times 25.24)0.67}{13.87}$ [5]	32.0 [6]	4.57	Moderate/both sides
Eagle West 2	$\frac{(4.57 \times 25.24)0.67}{13.87}$ [5]	144.0 [7]	5.57	Moderate/both sides
Mamm Creek	$\frac{(3.66 \times 20.73)0.67}{13.56}$ [5]	16.7	3.75	Light/both sides
Dry Creek	$\frac{(5.49 \times 24.38)0.67}{13.56}$ [5]	21.0	6.61	Light/both sides
Arch deer	$\frac{3.05 \times 6.10}{23.77}$	66.5	0.61	Light/both sides
Salida East 1	$\frac{5.49 \times 14.63}{11.25}$ [5]	124.0	5.17	Moderate/none
Salida East 2	$\frac{7.32 \times 14.63}{19.83}$ [5]	35.0	5.39	Moderate/none
Chaffee Gulch	$\frac{(3.66 \times 9.14)0.61}{13.56}$ [5]	15.4	1.51	Moderate/none

[1] Width (or open-end surface area) and length are measured parallel and perpendicular to direction of traffic, respectively. Formula is used to calculate openness or tunnel effect.

[2] All except the Arch, Salida, and Chaffee Gulch structures were adjacent to Interstate 70.

[3] Seasonal mean resulting from a 4-year study (Reed et al. 1975).

[4] Eagle West 1 and 2, Mamm Creek, and Dry Creek structures are twin bridges.

[5] Adjusted for irregular inside topography.

[6] Most passages occurred without completion of the 2.44-m fencing.

[7] Based upon use during one month. The 2.44-m fencing was completed to the structure about October 1, 1979.

Table 2. The number of deer crossings and approaches examined on video replay at the overpass and the crossings per approach (C:a) ratios for four migration seasons (Fall 1974 - Spring 1976).

Year/Season	Crossings	Distant 1/ Approach	Approach 2/	C:a
1974 Fall	99	-	2	49.5:1
1975 Spring	93	-	19	4.9:1
1975 Fall	77	-	3	25.7:1
1976 Spring	60	-	7	8.6:1
Totals/Avg.	329	-	31	10.6:1

1/ Denotes a deer that entered the overpass area not encompassed by an entrance and exit trackbed and that was oriented toward the structure. This overpass area was not covered by the video surveillance system during this period.

2/ Denotes a deer that entered either the entrance or exit trackbed area without crossing the overpass.

Table 3. The number of deer crossings and approaches examined on video replay at the experimental-variable-width overpass and the crossings per approach (C:a) ratios for four migration seasons (Fall 1976 - Spring 1978).

	Control				Variable				
	Crossings	Distant Approach 1/	Approach 2/	C:a	Crossings	Distant Approach	Approach	C:a	Total Crossings
1976									
Fall	25	-	5	5:1	19	-	5	3.8:1	44
1977									
Spring	41	-	4	10.2:1	19	-	4	4.8:1	60
1977									
Fall	31	2	0	15.5:1	13	4	7	1.2:1	44
1978									
Spring	26	0	4	6.5:1	14	7	8	0.9:1	40
Totals/Average	123	2	13	8.2:1	65	11	24	1.9:1	188

1/ Denotes a deer that entered the overpass area not encompassed by an entrance and exit trackbed and that was oriented toward the structure. The overpass area was that area covered by the video surveillance system during the fall of 1977 and the spring of 1978.

2/ Denotes a deer that entered either the entrance or exit trackbed area without crossing the overpass.

Table 4. The number of deer crossings and approaches examined on video replay at the experimental-net-arch overpass and the crossings per approach (C:a) ratios for two migration seasons (Fall 1978 - Springs 1979).

	CONTROL				VARIABLE				
	Crossings	Distant Approach[1]	Approach[2]	C:a	Crossings	Distant Approach	Approach	C:a	TOTAL Crossings
1978									
Fall	25	2	2	6.2:1	4	5	6	0.4:1	29
1979									
Spring	18	8	12	0.9:1	14	4	2	2.3:1	32
Totals/Avg.	43	10	14	1.8:1	18	9	8	1.1:1	61

1/ Denotes a deer that entered the overpass area not encompassed by an entrance and exit trackbed and that was oriented toward the structure.

2/ Denotes a deer that entered either the entrance or exit trackbed area without crossing the overpass.

Table 5. The mean duration (seconds) of hesitations and crossings during control and variable widths at the experimental-variable-width overpass.

	1976F[1]	1977S	1977F	1978S	TOTAL	P[2]
Hesitations						
Control	4.5±1.5[3](n=10)	13.2±14.2(n=29)	8.3±7.7(n=34)	9.2±6.9(n=30)	9.6±9.8(n=103)	$p > 0.20$
Variable	7.4±4.8(n=14)	4.9±3.5(n=6)	11.7±11.1(n=18)	15.7±14.7(n=26)	11.8±11.8(n=64)	
Crossings						
Control	7.4±4.9(n=25)	12.1±15.7(n=41)	8.4±5.3(n=27)	8.9±5.8(n=26)	9.6±10.3(n=119)	$p > 0.10$
Variable	8.3±3.8(n=19)	8.8±8.9(n=19)	4.8±4.9(n=11)	6.8±5.7(n=14)	7.5±6.3(n=63)	

1/ Fall or spring (F or S) migration periods.

2/ Independent t statistic.

3/ Standard deviation.

Table 6. The mean duration (seconds) of hesitations and crossings during control and variable at the experimental-net-arch overpass.

	FALL 1978	SPRING 1979	TOTAL	P[1]
Hesitations				
Control	10.2±12.4[2] (n=42)	16.3±19.4(n=49)	13.5±16.7(n=91)	P > 0.20
Variable	14.3±14.3(n=20)	7.2±4.6(n=20)	10.2±10.4(n=47)	
Crossings				
Control	7.2±12.4(n=25)	8.7±10.2(n=18)	8.0±11.4(n=43)	P > 0.40
Variable	24.2±19.8(n=4)	6.4±8.2(n=14)	10.4±13.3(n=18)	

[1] Independent t statistic.

[2] Standard deviation.

Table 7. The number of selected behavioral responses exhibited by deer crossing an experimental-variable-width overpass during four migration seasons (fall 1976, spring and fall 1977, and spring 1978) and calculated behavioral response ratios.

Behavioral Responses (BR)	No. of Animals Exhibiting BR (BR_a)	No. of Instances of BR (BR_i)	No. of Crossings (C)	BR_a:C[1]	BR_i:C	BR_i:BR_a
Muzzle-to-Ground [2]						
Control	32	55	123	0.26:1	0.45:1	1.72:1
Variable [3]	18	33	65	0.28:1	0.51:1	1.74:1
Muzzle-to-Structure [4]						
Control	20	24	123	0.16:1	0.20:1	1.20:1
Variable	15	22	65	0.23:1	0.34:1	1.47:1
Low-Head [5]						
Control	60	103	123	0.49:1	0.84:1	1.72:1
Variable	40	95	65	0.62:1	1.46:1	2.38:1
Hesitation [6]						
Control	62	103	123	0.50:1	0.84:1	1.66:1
Variable	42	66	65	0.65:1	1.02:1	1.57:1
Alert Stance [7]						
Control	33	63	123	0.27:1	0.51:1	1.91:1
Variable	34	57	65	0.52:1	0.88:1	1.68:1

[1] C denotes the number of crossings during the four seasons.

[2] Muzzle-to-ground denotes a deer lowering its muzzle to the ground.

[3] Control and variable widths were 4.93 m and 2.48 m, respectively.

[4] Muzzle-to-structure denotes a deer lowering its muzzle to the bridge deck or raising its muzzle to the bridge railing.

[5] Low-head denotes a lowering of the head where the axis of the neck declines (posterior to anterior) below the horizontal.

[6] Cessation of forward movement for 1.0 second or more.

[7] Alert stance denotes a position where the head and neck are above horizontal and the ears are erect with the vertical axis of the ear either perpendicular to horizontal or inclined forward.

Table 8. The number of selected behavioral responses exhibited by deer approaching or crossing an experimental-net-arch overpass during two seasons (fall 1978 and spring 1979) and calculated behavioral response ratios.

Behavioral Responses (BR)	No. of Animals Exhibiting BR (BR_a)	No. of Instances of BR (BR_i)	No. of Crossings (C)	BR_a:C[1]	BR_i:C	BR_i:BR_a
Muzzle-to-Ground [2]						
Control	15	33	43	0.35:1	0.77:1	2.20:1
Variable [3]	6	9	18	0.33:1	0.50:1	1.50:1
Muzzle-to-Structure [4]						
Control	16	25	43	0.37:1	0.58:1	1.56:1
Variable	8	15	18	0.44:1	0.83:1	1.88:1
Low-Head [5]						
Control	39	102	43	0.91:1	2.37:1	2.62:1
Variable	18	55	18	1.00:1	3.06:1	3.06:1
Hesitation [6]						
Control	48	91	43	1.12:1	2.12:1	1.90:1
Variable	22	47	18	1.22:1	2.61:1	2.14:1
Alert Stance [7]						
Control	7	9	43	0.16:1	0.21:1	1.29:1
Variable	2	7	18	0.11:1	0.39:1	3.50:1

[1] C denotes the number of crossings during the two seasons.

[2] Muzzle-to-ground denotes a deer lowering its muzzle to the ground.

[3] Control was a 2.48 m wide bridge and the variable was the same bridge with a net arch similar to those used on pedestrian overpasses.

[4] Muzzle-to-structure denotes a deer lowering its muzzle to the bridge deck or raising its muzzle to the bridge railing.

[5] Low-head denotes a lowering of the head where the axis of the neck declines (posterior to anterior) below the horizontal.

[6] Cessation of forward movement for 1.0 second or more.

[7] Alert stance denotes a position where the head and neck are above horizontal and the ears are erect with the vertical axis of the ear either perpendicular to horizontal or inclined forward.

Table 9. Responses of seven mule deer to prototype II deer guard, 3.05 m wide X 3.66 m long and constructed with flat mill steel rails painted in 30-cm long alternating black and white sections.

Result	Predominate mode of crossing	Number of bend-neck-looks 1/	Number of approaches 2/	Sex/age 3/	Time from release to completed crossing (sec.)
Crossed	bound	0	1	F/	67.2
Crossed	trot	1	3	F/	354.1
No crossing	----	0	1	F/F	--
Involuntary crossing	walk	5	3	M/F	100.6
Crossed	trot	1	5	M/F	107.0
Crossed	walk	2	1	F/	30.4
Crossed	walk	0	1	F/	67.0

1/ Bend-neck-look denotes a visible sensory inspection exhibited by bending neck, moving ears forward, and apparently looking at guard.

2/ Approach denotes instances when subject comes within 1 m of guard and goes onto or turns away from the structure.

3/ Male or female is indicated by an M or F before the slash (/). Fawn is indicated by an F after the slash. All others were yearling or mature.

Table 10. Responses of 14 mule deer to prototype III deer guard (five truck tire tubes cut, sectioned longitudinally, and stretched across and 15 cm above prototype II).

Result	Predominate mode of crossing	Number of bend-neck-looks	Number of approaches	Number of walk-ons [1/]	Sex/age	Time from release to completed crossing (sec.)
No crossing	----	1	5	-	F/	--
Crossed	walk	0	3	2	M/F	83.8
Crossed	walk	9	11	3	F/	1,653.0
Crossed	bound	0	1	0	F/	7.0
Crossed	trot	0	1	1	M/	41.0
Involuntary crossing	----	10	3	1	F/F	790.0
No crossing	----	0	1	0	M/	--
No crossing	----	0	27	0	F/	--
Crossed	walk	12	6	4	F/F	380.0
Crossed	walk	2	3	1	F/	476.6
No crossing	----	0	0	0	F/F	--
Crossed	walk	3	3	2	M/	835.0
Crossed	walk	3	4	3	M/	508.2
Crossed	bound	0	1	1	F/	83.6

1/ Walk-on denotes instances when subject walked onto the stretched tubing and backed off or turned around returning to solid ground.

Table 11. Responses of eight mule deer to prototype IV deer guard (93 ten-speed bicycle tire tubes cut and stretched across and 15 cm above prototype II).

Result	Predominate mode of crossing	Number of bend-neck-looks	Number of approaches	Number of walk-ons	Sex/age	Time from release to completed crossing (sec.)
Crossed	trot	2	3	1	M/	990.0
Crossed	trot	0	1	0	M/	15.6
No crossing	----	0	1	0	M/	--
Crossed	bound	1	2	1	F/F	174.5
No crossing	----	0	0	0	F/F	--
Crossed	walk	5	3	1	F/	492.3
Crossed	bound	0	0	0	F/	300.0
No crossing	----	7	9	0	M/F	--

Table 12. Responses of four mule deer to prototype V deer guard (black and white scintillation or rotary motion pattern described by McKay [1957]).

Result	Predominate mode of crossing	Number of bend-neck-looks	Number of approaches	Number of walk-ons	Sex/age	Time from release to completed crossing (sec.)
Crossed	walk	7	2	1	F/Y	1,765.0
Crossed	walk	3	2	1	M/Y	124.3
Crossed	bound	0	1	0	F/M or Y	5.2
Crossed	walk	17	6	4	F/M or Y	647.3

Table 13. The prototype, number of deer tested, bend-neck-looks (investigative behavior) per crossing (xing), walk-on per xing, and xing per involuntary or no xing ratios for five deer guard designs.

Prototype No.	n	Ratios		
		bend-neck-look:xing	walk-on:xing	xing:involuntary or no xing
I [1/]	18	3.1:1	----	8.0:1
II	7	0.8:1	----	2.5:1
III	14	3.2:1	1.9:1	1.8:1
IV	8	1.6:1	0.6:1	1.7:1
V	4	6.8:1	1.5:1	----

1/ As reported by Reed et al. (1974b).

Table 14. The mean annual number or pre- and post-installation deer highway kills and percent reduction for six 2.44-m fences adjacent to Interstate 70 and Highway 82.

Fence (Hwy)	Length of hwy fenced km (Miles)	Mean annual pre-installation mortality	Mean annual post-installation mortality	Percent reduction mortality
Vail (I-70)	2.4 (1.5)	36 (3)1/	11.6 (10)1/	67.8
Avon (I-70)	3.6 (2.3)	28 (1)	3.9 (7)	86.1
Edwards (I-70)	3.6 (2.3)	27 (1)	5.7 (7)	78.9
Eagle (I-70)	7.7 (4.8)	167 (1)	22.5 (6)	86.5
Diamond S (82)	1.8 (1.1)	10 (3)	1.8 (8)	82.0
Carbondale (82)	1.8 (1.1)	14 (5)	4.2 (5)	70.0
Cumulative Avg.				78.5

1/ (n) denotes the number of years of pre- and post-installation data.

Table 15. Mean number of deer observed on spotlight counts and mean number of deer crossings between quarter-mile section markers 25 to 30 on Highway 82 during March-May for 1968 through 1976 (n = number of counts or number of 24-hour periods).

Year	March	April	Mean Total	Mean Mar.-May Crossings
1968	134.8 (n=4)	73.0 (n=4)	103.9 (n=8)	
1969	151.2 (n=4)	34.0 (n=5)	86.1 (n=9)	
1970	104.5 (n=4)	56.0 (n=5)	77.6 (n=9)	
1971	66.8 (n=4)	51.4 (n=5)	58.4 (n-9)	11.7 (n=32)
1972	102.2 (n=4)	4.5 (n=4)	53.4 (n=8)	2.1 1/ (n=38)
1973	137.4 (n=5)	47.0 (n=4)	97.2 (n=9)	5.5 (n=34)
1974	143.5 (n=4)	52.3 (n=3)	104.4 (n=7)	10.3 (n=38)
1975	126.8 (n=4)	93.0 (n=4)	109.9 (n=8)	17.8 (n=73)
1976	78.0 (n=4)	61.8 (n=4)	69.9 (n=8)	21.0 (n=28)

1/ 1.77 km of 2.44-m fence constructed during summer of 1971.

Table 16. Female and male deer mean lateral movements (km) along or adjacent to the field side or highway side of 2.44-m fences at Vail, Avon, and Eagle as determined under several conditions.

	Vail		Avon		Eagle	
Side of Fence	Female	Male	Female	Male	Female	Male
Field Side						
Apparent [1/]	0.900(n=3)[2/]	0.500(n=2)	0.578(n=2)	--	0.588(n=107)	0.762(n=34)
Observed [3/]	0.272(n=8)	0.350(n=1)	0.280(n=1)	--	--	--
Highway Side						
Apparent	--	--	--	--	0.617(n=3)	0.480(n=4)
Observed	0.350(n=1)	--	0.500(n=5)[4/]	0.506(n=4)	--	1.207(n=2)
Observed and harassed [5/]	--	--	--	--	0.975(n=4)	0.646(n=5)

1/ Movements estimated by noting the locations of radio-collared or neckbanded deer at selected points along the fences at widely separated time periods.

2/ (n) denotes number of lateral distances.

3/ Movements observed during their duration.

4/ Included one distance that was the "net" lateral movement occurring during a period of 45 minutes. Twenty-two changes in direction or mini-lateral movements occurred during this "net" movement. The mean mini-lateral movement was 140.9±154.8(SD) m.

5/ Animals were usually chased with a vehicle at night until they either escaped from the fenced side of the highway or "broke" back against the vehicle.

Table 17. The number of one-way deer gates and mean annual number of passages through one-way gates located in four Interstate 70 2.44-m fences.

2.44 Fencing Location	Number of One-way Gates	Mean Annual One-way Gate Passage
Vail - both sides	7 (7) 1/	73.6 (9) 2/
Avon - one side	6 (9)	70.6 (7)
Edwards - one side	5 (7)	6.4 (7)
Eagle - one side	10 (10)	13.5 (6)

1/ (N) denotes the number of gates originally installed in the 2.44-m fence. In this case, two gates were removed and two installed at new locations. In cases where one-way gates received little use (< 3 passages per year) and/or considerable human interference, they were removed and the openings fenced.

2/ (n) denotes number of years of post-installation data. One black bear passage occurred during 1974.

Table 18. Visibility index measurements from accident sites in transition lighting.

No.	Background luminance (fL)	Target luminance (fL)	Contrast	Relative Contrast Sensitivity (%)	Visibility Index[a]
1	0.019	0.025	0.311	2.21[b]	0.120
2	0.010	0.115	10.058	1.37[b]	2.395
3	0.066	0.006	- 0.916	5.53	- 0.882
5	0.103	0.011	- 0.898	7.30	- 1.142
6	1.480	0.008	- 0.995	27.70[b]	- 4.800
7	0.124	0.013	- 0.899	8.23	- 1.289
9	0.043	0.033	- 0.244	4.10	- 0.174
10	0.226	0.003	- 0.987	11.80	- 2.029
11	0.330	0.003	- 0.990	14.40	- 2.484
12	0.061	0.009	- 0.846	5.25	- 0.774
13	0.235	0.026	- 0.891	12.05	- 1.870
14	0.060	0.005	- 0.920	5.20	- 0.833
15	0.285	0.004	- 0.986	13.33	- 2.289
16	0.080	0.017	- 0.794	6.20	- 0.858
18	0.086	0.130	0.512	6.50	0.580
19	0.180	0.011	- 0.939	10.40	- 1.701
21	0.180	0.026	- 0.856	10.40	- 1.551
22	(0.690)[c]	0.284	- 0.600	20.31	- 2.134
23	0.690	0.012	- 0.983	20.31	- 3.477
26	0.253	0.247	- 0.024	12.53	- 0.052

Table 18. Visibility index measurements from accident sites in transition lighting. (Continued).

No.	Background luminance (fL)	Target luminance (fL)	Contrast	Relative Contrast Sensitivity (%)	Visibility[a/] Index
27	0.066	0.260	2.939	5.55	2.842
28	0.279	0.136	- 0.513	13.20	- 1.179
31	0.041	0.006	- 0.839	4.00	- 0.585
32	0.280	0.009	- 0.968	13.22	- 2.228
33	0.400	0.020	- 0.951	15.85	- 2.625
36	0.045	0.475	9.556	4.25	7.075

a/ Positive and negative values indicate frontlighting and backlighting, respectively.

b/ Derived from data presented by Technical Committee Report of the CIE 1972.

c/ Background at this site involved a snow covered emergency lane and right-of-way. The snow was lost before measurement. A value for similar conditions (No. 23) was used.

Table 19. Visibility index measurements from accident sites in full lighting.

No.	Background luminance (fL)	Target luminance (fL)	Contrast	Relative Contrast Sensitivity (%)	Visibility Index[a/]
4	0.630	0.390	- 0.381	19.62	- 1.303
8	1.100	0.209	- 0.810	24.44	- 3.449
17	0.240	0.470	0.958	12.20	2.036
20	0.197	0.069	- 0.650	10.95	- 1.240
24	0.185	0.178	- 0.038	10.57	- 0.070
25	0.237	0.455	0.920	12.10	1.939
29	0.075	0.120	0.600	5.95	0.622
30	0.500	0.110	- 0.780	17.67	- 2.401
34	0.420	0.140	- 0.667	16.24	- 1.886
35	0.580	0.330	- 0.431	18.98	- 1.425
37	0.620	0.270	- 0.565	19.51	- 1.919
38	0.440	0.108	- 0.755	16.63	- 2.186
39	0.225	0.480	1.133	11.77	2.323

[a/] Positive and negative values indicate frontlighting and backlighting, respectively.

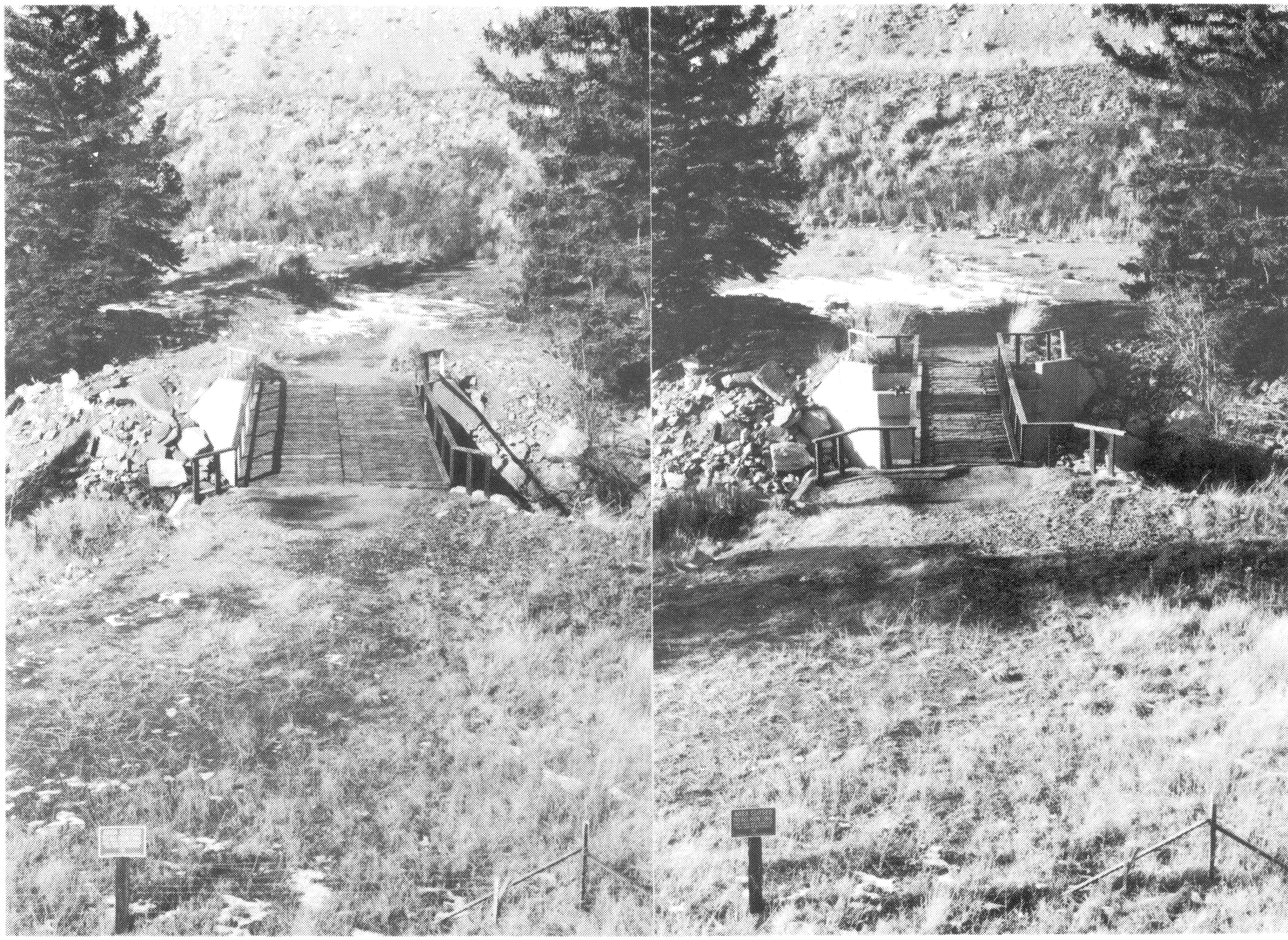

Fig. 1. The control (4.93 m) and variable (2.48 m) widths (left and right, respectively) of the deer overpass over Gore Creek. Photos by D. F. Reed.

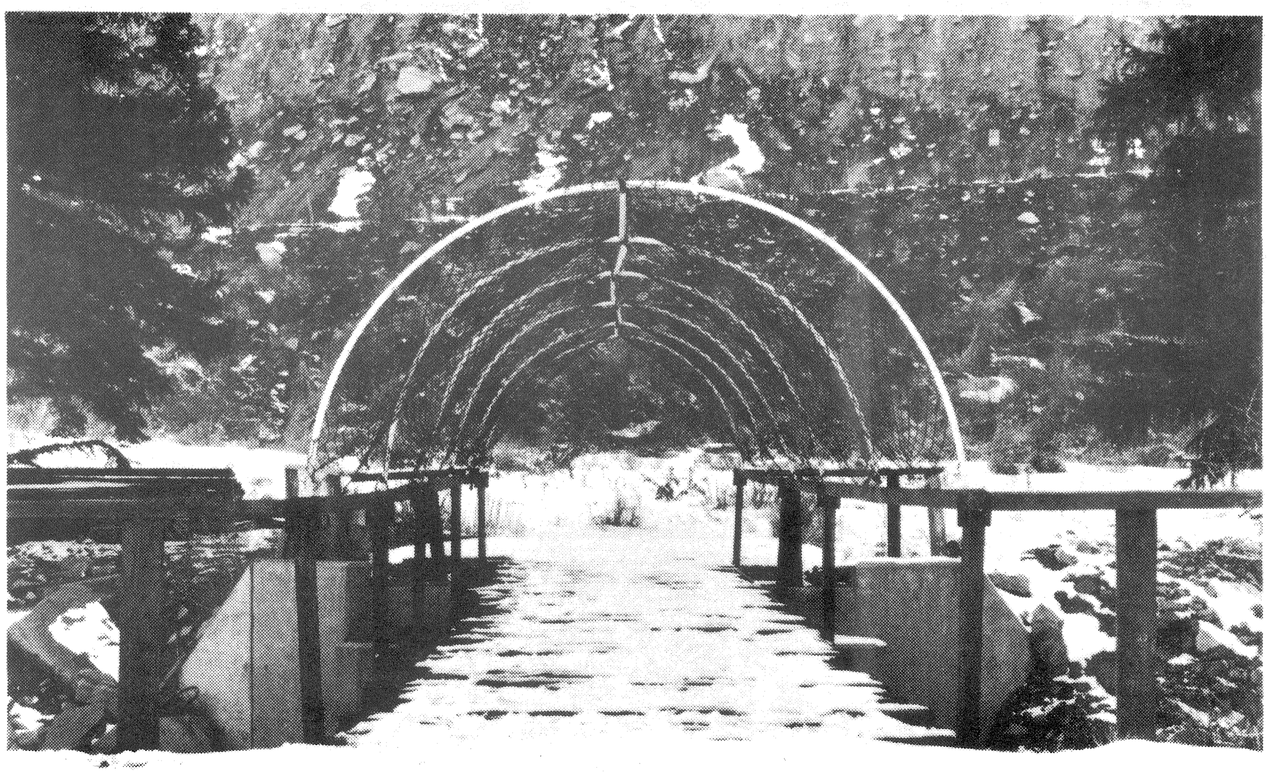

Fig. 2. The overhead netting assembled (variable) on the deer overpass. Photo by D. F. Reed.

Fig. 3. A one-way deer gate showing a deer bounding through the structure. Photo by D. F. Reed.

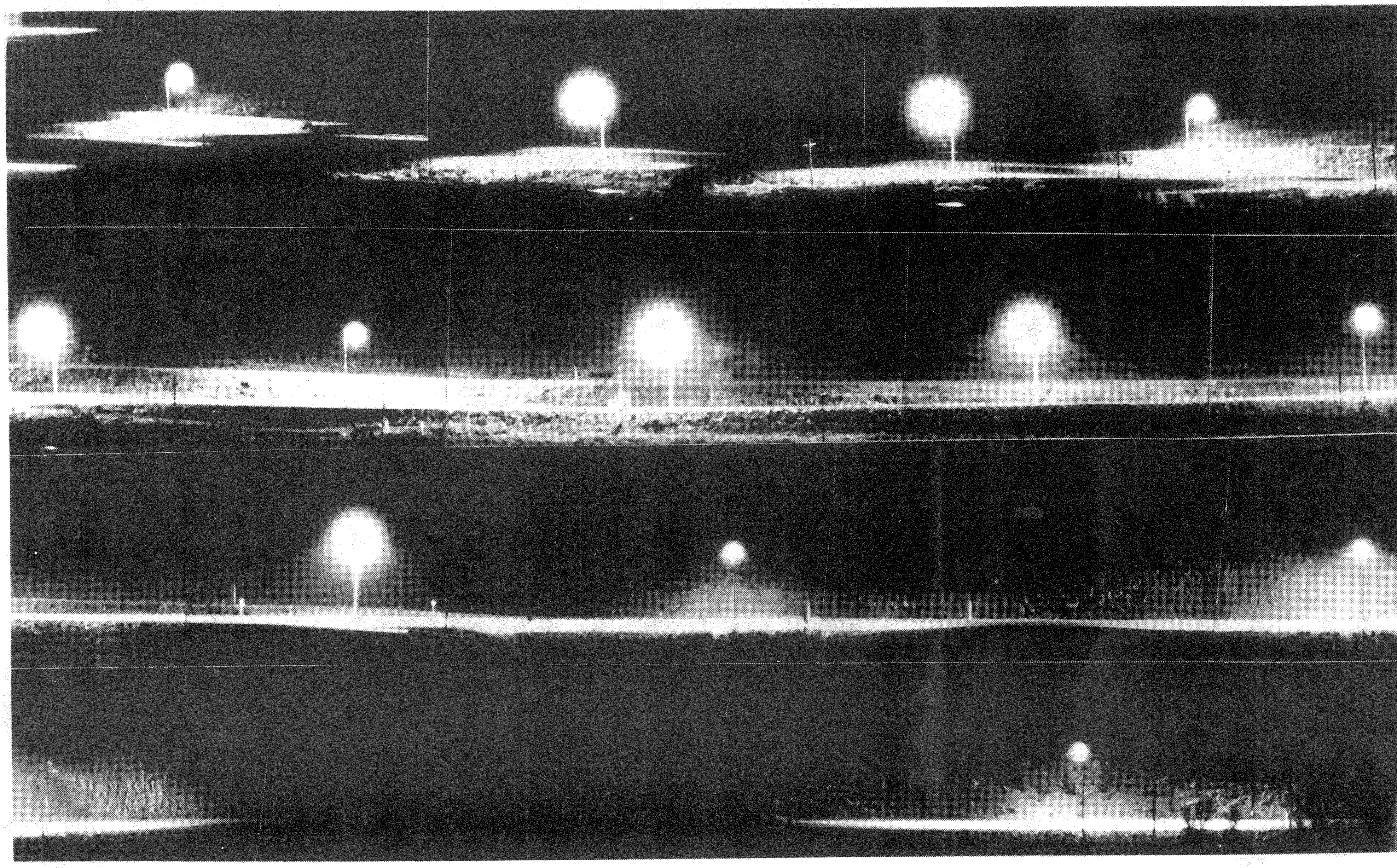

Fig. 4. A panorama of the lighting (13 luminaires) located (left to right, top to bottom, northwest to southeast of the study area) on Highway 82. Photos by D. F. Reed.

Fig. 5. The Spectra Model UBA spotmeter shown on the right was used to measure the target (deer simulation shown at center) and background (highway surface and dark background beyond the simulation) luminances. Photo by D. F. Reed.

Fig. 6. The lighted, animated deer crossing sign is shown turned toward traffic with the lighted silhouette sequence beginning. Photo courtesy of the Colorado Division of Highways.

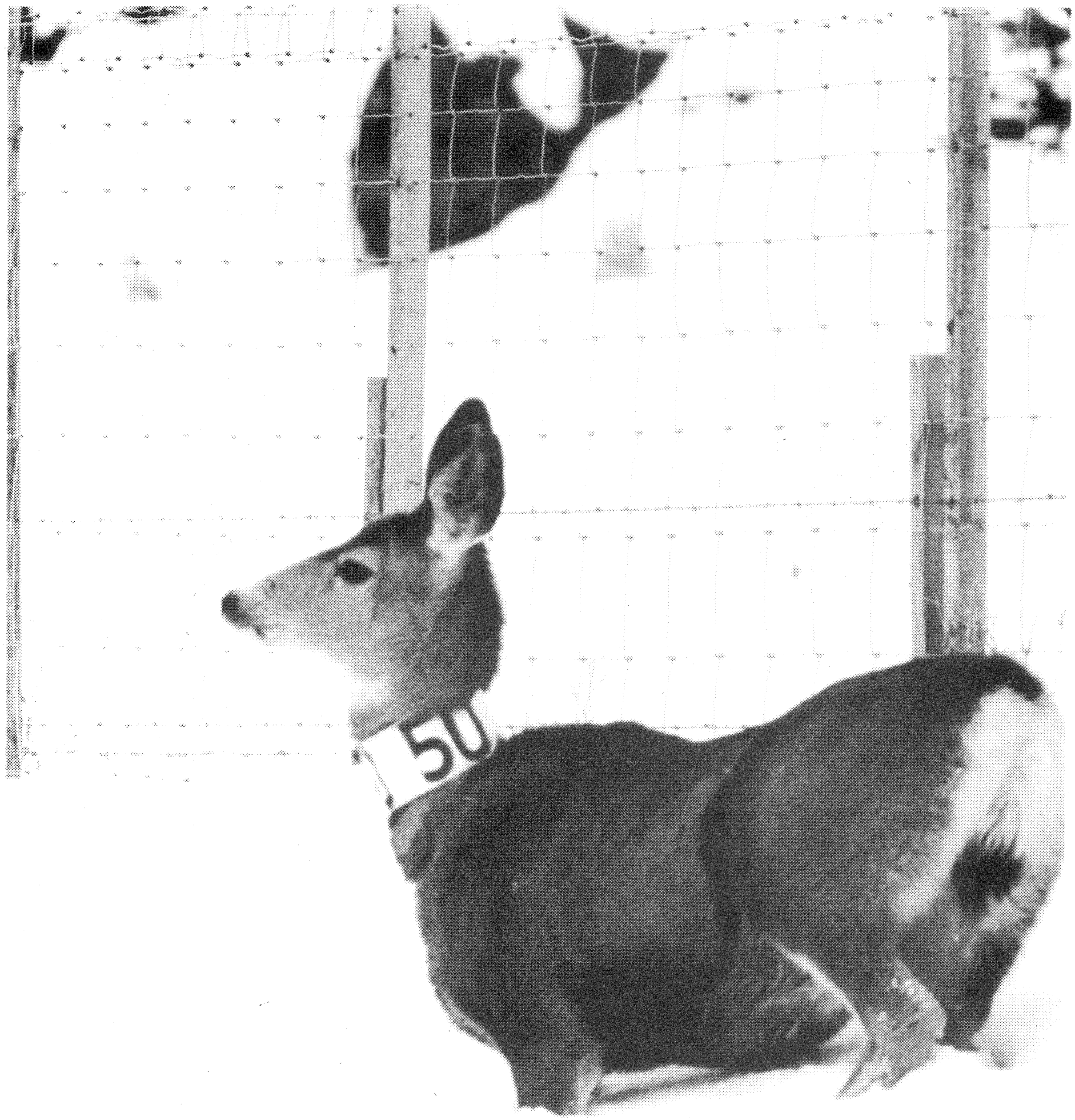

Fig. 7. Neck banded doe number 50 near the 2.44-m fence east of Eagle and adjacent to I-70. Photo by L. L. Green.

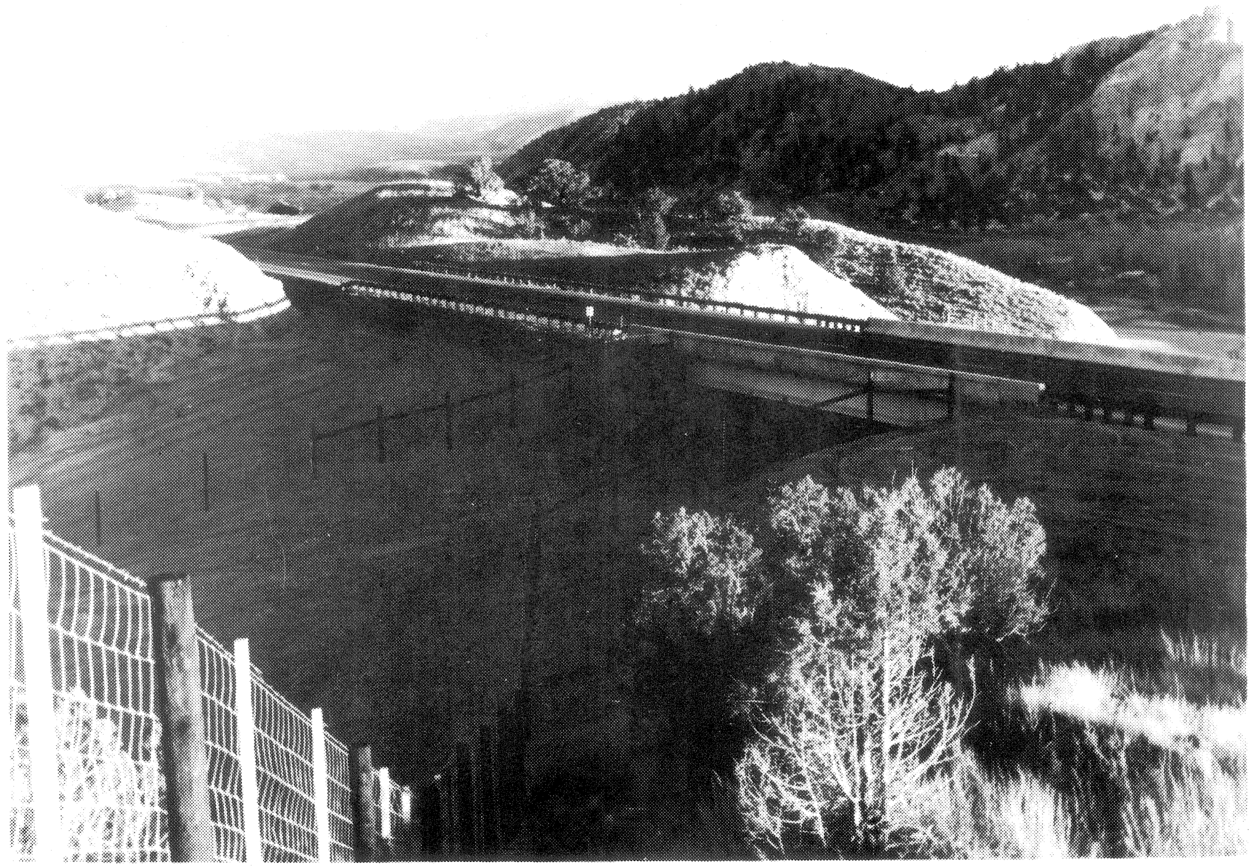

Fig. 8. The Eagle West 2 bridge underpass under the west bound lanes of I-70. The 2.44-m fencing adjoins the bridge abutments. Photo by D. F. Reed.

Fig. 9. Reportedly plastic strip curtains have kept animals inside game parks in West Germany's Harz Forest Region. Effectiveness was based on light reflection from the plastic strips. AP photo.